Attachment 2 to Paper No. 11

MARKED UP VERSION OF SUBSTITUTE SPECIFICATION

An averaging pitot tube generally includes a shaped bluff body that slightly impedes fluid flow within the conduit. One limitation of some averaging pitot tubes is a relatively lower signal to noise ratio in the differential pressure data being sensed. "Noise" in the context of a differential pressure measuring device, such as a flow transmitter, is the instantaneous deviation from an average pressure reading from one data point to another. The noise generated in a pitot tube type of differential pressure sensor originates in the impact pressure [sensors] ports on the upstream facing side of the pitot tube and in the low pressure ports on the downstream side of the pitot tube.

As differential pressure transmitters and data acquisition systems have become more sophisticated and responsive, they have also become more sensitive to and are increasingly influenced by the noise generated by the pressure sensing unit. Accordingly, the noise characteristics of differential pressure sensing devices[, such as flow transmitters,] have become a more important factor in their selection and operation. Thus, there is a need to provide an improved differential pressure sensing device [having] with an improved signal to noise ratio.

Fig[s]. 3[a and 3b are] is a system block diagram[s] of the process measurement system [12 and differential pressure measurement probe 20, respectively].

Fig[s]. 10 [- 12 are] is a chart[s] of pressure versus time illustrating [the] typical noise [reduction] characteristics of [embodiments of the invention] prior art pitot tube type of differential pressure measuring probe, such as the probe disclosed in U.S. Patent No. 4,559,836.

Figure 11 is a chart of pressure versus time illustrating the improved noise characteristics of the differential pressure measuring probe of the present invention.

Fig. 1 is a diagrammatic view of a process control system 10, illustrating one example of an environment [of] for embodiments of the invention. Pressure measurement system 12 is coupled to control room 14 (modelled as a voltage source and resistance) through process control loop 16. Loop 16 can utilize any appropriate protocol to communicate flow information between measurement system 12 and control room 14. For example, process control loop 16 operates in accordance with a process industry standard protocol such as Highway Addressable Remote Transducer (HART®), FOUNDATION™ Fieldbus or any other appropriate protocol.

Fig. 2[,] shows a cut away portion of a process fluid container such as a pipe, or closed conduit, 18 into which is installed a differential pressure measuring probe 20 of the averaging pitot tube type. The bluff body 22 of probe 20 is constructed in accordance with an embodiment of the invention that will be described in greater detail later in the specification. Bluff body 22 diametrically spans the inside of pipe 18. The directional arrow 24 in Fig. 2 indicates the direction of fluid flow in the pipe 18. A fluid manifold 26 and flow transmitter 13 are shown mounted on the exterior end of pitot tube 20. Transmitter 13 includes a pressure sensor 28 that is [fluidically] fluidly coupled to probe 20 through passageways 30 (shown in phantom in Fig. 2).

Fig[s]. 3[a and 3b are] is a system block diagram[s] of differential pressure measurement system 12 [and differential pressure measurement probe 20, respectively]. System 12 includes flow transmitter

13 and differential pressure measurement probe 20. System 12 is coupleable to a process control loop such as loop 16 and is adapted to communicate a process variable output related to a differential pressure of fluid flow within pipe 18. Transmitter 13 of system 12 includes a loop communicator 32, pressure sensor 28, measurement circuitry 34, and controller 36.

Measurement circuitry 34 is coupled to sensor 28 and is configured to provide a sensor output related to the differential pressure that exists between ports 38 and 40. Measurement circuitry 34 can be any electronic circuitry that can provide a suitable signal related to differential pressure. For example, measurement circuitry can be an[d] analog-to-digital converter, a capacitance-to-digital converter or any other appropriate circuitry.

Controller 36 is coupled to measurement circuitry 34 and loop communicator 32. Controller 36 is adapted to provide a process variable output to loop communicator 32, which output is related to the sensor output provided by measurement circuitry 34. Controller 36 can be a [P]programmable [G]gate [A]array device, microprocessor, or any other appropriate device.

Differential pressure measurement probe 20 is coupled to transmitter 13 by passageways 30. Thus, port 38 of sensor 28 is coupled to a first plenum 42, while port 40 of sensor 28 is coupled to a second plenum 44. A "plenum" is a passageway, a channel, a tube or the like into which fluid of a particular character or pressure is directed [of] or admitted and through which [the] fluid pressure is [conducted] communicated, [or] conveyed or transmitted.

The bluff body 22 includes a [F]first plenum 42, [includes] a longitudinally extending impact surface 46 with at least one impact aperture

48 disposed to communicate fluid pressure from the impact surface 46 through the plenum 42 and conduits 30 to port 38 of sensor 28. In [some] various different embodiments, the impact surface 46 [has] may have a width ranging between about 12.7 millimeters (0.50 inches) to about 50.8 millimeters (2.00 inches). As shown in Figs. 2, 4, and 5, substantially all of impact surface 46 is normal to the upstream direction of fluid flow which is indicated by arrow 24. As can be seen from Figs. 2 and 4 - 8, the at least one impact aperture 48 can have any appropriate width. For example, aperture 48 can have a width between about 0.762 millimeters (0.030 inches) and about 6.35 millimeters (0.250 inches). [Thus, a] A ratio of plenum width to aperture width greater than about 8:1 appears to provide beneficial results. [Additionally aperture] Aperture [42] 48 can take the form of a longitudinally extending slit or any other shape, including the traditional circular or oval opening. [Such] A slit opening provides enhanced noise reduction in the impact pressure signal, and thus increases the signal to noise ratio of the measurement system. When a slit is used, it is important for the width of the slit to be less than an interior width of the plenum [to] with which it is [connected] in communication. [Additionally, a] A plurality of slits can be used [which can be] that are spaced from one another laterally, or longitudinally. Further still, slits can be used for the downstream apertures as well as circular openings.

Second plenum 44 includes a non-impact surface 50 spaced from impact surface 46. Surface 50 includes at least one non-impact aperture 52 disposed to communicate pressure from the non-impact surface via plenum 44 to port 40 of sensor 28. As can be seen in Figs. 2, and 4 - 8, a variety of geometries can be used with embodiments of the invention. Generally, with each embodiment at least one of the first and second plenums 42, 44 is shaped to create a fluid stagnation point at the at least

one non-impact aperture 52. If a second plenum is not needed, a pressure tap can be provided in the wall of pipe 18 such that non-impact aperture 52 is disposed within pipe 18 to communicate a non-impact pressure to port 40. For example, aperture 52 can be disposed proximate an inside wall of pipe 18. Additionally, flow transmitter 13 and probe 20 can be factory matched to provide enhanced accuracy, longevity and diagnostics for a particular differential flow measurement application.

Figs. 4 and 5 respectively show fragmentary perspective and cross sectional views of the bluff body portion 22 of the pitot tube 20[, respectively]. As illustrated, a cross section of the bluff body resembles the letter "T", including a bar portion 54 having a blunt, substantially flat [face] impact surface 46 on the "top" of the letter "T". The cross section of the body also illustrates the stem portion 56 of letter "T, " depending from the center of the bar 54 and disposed generally perpendicularly thereto. In [a] the perspective [or in a side] view of the bluff body (Fig.4) the so-called "stem" of the "T" is seen to be a longitudinally extending rib 56 that projects in a downstream direction from the back side of the flat faced bar 54.

In order to increase the signal-to-noise ratio of the low pressure measurement, the ratio of length to width (L/W) of bluff body 2z, as shown in Fig. 4, should be greater than about one half (1/2) and less than about one and one half (1 1/2). A ratio of one (1) appears to provide the advantageous results.

The [F]first and second plenums 42 and 44 are disposed along the length of and within the bluff body and extend into the portion of the pitot tube 20 that projects outside of fluid-carrying conduit 18 to flow transmitter 13.

Fig. 2 shows the bluff body 22 oriented within fluid-carrying conduit 18 so that the blunt, flat impact surface 46 [proximate bar 54] faces

the <u>fluid</u> flow front and is perpendicular to the direction of fluid flow 24. Such orientation provides a relatively large dome of high pressure extending across surface 46, and thus creates a more effective impact stagnation zone. The projecting rib 56 is generally parallel to the direction of fluid flow in the conduit 18.

The normal plurality of <u>circular</u> high pressure [sensing] <u>conducting</u> apertures in the upstream <u>facing</u> surface of a bluff body of a traditional averaging pitot tube [can be] <u>are</u> replaced, [in one embodiment of the invention,] <u>in the embodiments shown in the drawings,</u> with one or more narrow slit openings, each positioned [laterally] centrally <u>widthwise</u> of bar portion 54 and extending longitudinally substantially the entire length of bluff body 22. The slits provide communication between the high pressure (impact) fluid in conduit 18 and plenum 42 thus conducting the impact pressure of the flowing fluid into plenum 42 and to port 38 of pressure sensor 28 within flow transmitter 13. As opposed to a plurality of spaced apart circular apertures, the slit configuration provides a further reduction in the noise associated with the measurement of the high fluid pressure, provided that the narrow slit serves as the entry to a wider and larger plenum. In order to achieve the noise reduction, the slit should not act as the plenum itself. For example, if the slit in the bar face is 0.762 millimeters (0.030 inches) wide and plenum 42 is 3.2 millimeters (0.125) inches wide, a satisfactory ratio would exist. These dimensions and the ratio are exemplary only and should not be taken as restrictive or limiting.

The non-impact fluid is directed into second plenum 44 in pitot tube 20 through one or more downstream apertures 52, or alternatively, a longitudinally extending slit, located behind bar 54 of the bluff body 22. As shown in Fig. 5, bar portion 54 of bluff body 22 creates shedding vortices in the fluid flowing around edges 58 and 60 of the lateral extremities of bar

54, producing stagnation of the fluid in the area adjacent the back side 50 of the bar 54 and around the lateral sides of projecting rib 56. The main function of the rib 56 of the "T" shaped embodiment is to extend, in a downstream direction, the point of reattachment of the fluid vortices that are created by the lateral edges 58 and 60 of the flat faced bar 54. Deferring reattachment of the vortices increases the size of the stagnation zone, thus reducing the residual noise in the low pressure component of the differential pressure measurement.

The blunt impact face of the bluff body, together with the rounded lateral edges, produce enhanced fluid flow characteristics and shedding vortices that provide the noise reducing quiescence in the flowing fluid. Although one embodiment of the invention utilizes an impact surface that would, in ordinary parlance, be considered "flat, " it is apparent that an impact face that departs somewhat from the nominal "flat" surface can also be used. For example, a slightly convex surface would suffice, as well as a moderately undulating, roughened or scalloped surface. A concave surface would preserve the fluid flow characteristics and its lateral edges would provide the requisite flow separation. Accordingly, for purposes of the description of the invention and the accompanying claims, "flat" means a surface having a convex, or upstream facing, deviation from a nominal flat surface of not more than 0.134 times the width of the bluff body (0.134 x W) or having an unlimited concave deviation from a nominal flat surface.

Additional embodiments of the invention are shown in Figs. 6-8. In each, the blunt, flat impact face having one or more narrow high pressure fluid admitting slit openings is a common feature. The primary difference between the alternative embodiments and the embodiment described above is the shape and position of the downstream depending extensions of the bar that provide delay in the reattachment of the vortices.

Different designs of the downstream extension result in variation of the shape and size of the fluid stagnation zones. Selection of the particular form or design of the bluff body's extension member may depend on several factors incident to the measuring environment, such as, for example, cost, the character of the fluid, the range of fluid flow rates [of] or the size of the conduit carrying the fluid, among others.

Fig. 7 illustrates a "V" shaped form of a bluff body 22b having a flat faced bar portion [54b] 34b that faces upstream and is provided with the same [plurality of] one or more longitudinally extending impact slits 48b and a first plenum 42b[, as in the previously discussed embodiments]. The downstream extension for deferring reattachment of fluid vortices takes the form of a pair of projecting ribs or legs 74 and 76, depending from the lateral extremities of the back side of the bar [54b] 34b and diverging outwardly into the stream of flowing fluid. As between the bar edges 78 and 80 and the outside lateral edges 82 and 84 of the legs 74 and 76, the lateral edges [86] of the legs (the lateral edges of the fluid profile of the body) create the greatest amount of separation of the fluid boundary layer, producing a zone of fluid quiescence between the legs. The width L_1 of the bar [54b] 34b should be less than or equal to total width L_2 of the total bluff body. A plurality of longitudinally spaced apart non-impact apertures 52b are located on the interior sides of the legs 74, 76 and communicate with second plenums 44b in the body of the legs to convey the low pressure fluid to the pressure transducer.

[Figs. 10 - 12 are charts of pressure versus time illustrating the noise reduction of embodiments of the invention. Fig. 10 illustrates a sample pressure chart of a differential pressure measurement probe in accordance with the prior art. Fig. II illustrates a sample pressure chart measured from a probe incorporating an impact slit as shown in Figs. 2 and

4 - 8. Fig. 12 illustrates a sample pressure chart measured from a probe incorporating both the substantially flat impact surface, and the longitudinally extending slit shown in Figs. 2 and 4 – 8. As shown in Figs. 10 - 12, appreciable noise reduction in a differential pressure measurement system can be achieved. Such noise reduction provides for quicker calculation of an accurate indication of differential pressure, thus potentially providing more effective process control]. Figure 10 is an exemplary chart showing the noise characteristics of a prior art differential pressure measurement probe, such as the one illustrated in U.S. Patent No. 4,559,836. Figure 11 is a similar chart to that of Figure 10, however, Figure 11 illustrates the noise characteristics of the differential pressure measurement probe of the present invention that incorporates both the substantially flat impact surface, and the longitudinally extending slit shown in Figs. 2 and 4 – 8. As shown by these charts, appreciable noise reduction in a differential pressure measurement system is achieved by the present invention. Such noise reduction provides for quicker calculation of an accurate indication of differential pressure, thus potentially providing more effective process control.

Attachment 3 to Paper No. 11

MARKED UP VERSION OF AMENDED CLAIMS

1. (amended) A differential pressure measurement probe adapted for placement within a fluid-carrying conduit, the probe comprising:

a [first] high pressure plenum configured to couple to a first pressure sensor port, the first plenum including an impact surface with at least one impact aperture disposed therein to communicate pressure from the impact surface to the first pressure sensor port;

a non-impact surface spaced from the impact surface, the non-impact surface having at least one non-impact aperture disposed therein to communicate pressure from the non-impact surface to a second pressure sensor port; and

wherein the impact surface extends longitudinally and is substantially flat, such that fluid within the conduit impinges upon the substantially flat impact surface.

2. (amended) The probe of claim 1, and further comprising a [second] low pressure plenum, and wherein the non-impact surface is disposed on the second plenum.

3. (amended) The probe of claim 2, wherein the [first] high and [second] low pressure plenums are spaced by a longitudinal rib configured to extend downstream.

5. (amended) The probe of claim 2, wherein the [second] low pressure plenum is shaped to include a longitudinally extending rib portion coupled to the first plenum.

9. (amended) The probe of claim 2, wherein the [second] <u>low pressure</u> plenum is shaped to include a pair of longitudinally extending rib portions diverging angularly with respect to the impact surface.

11. (amended) The probe of claim 2, wherein the [second] <u>low pressure</u> plenum is shaped to include a pair of spaced apart longitudinally extending rib portions each disposed perpendicular to the impact surface.

12. (amended) The probe of claim 1, wherein the [first] <u>high pressure</u> plenum has a plenum width and the impact surface is shaped to create a localized region of relatively high pressure across substantially the entire plenum width.

15.(amended) The probe of claim 1, wherein the [first] <u>high pressure</u> plenum has a plenum width, the at least one impact aperture has an aperture width, and wherein the ratio of plenum width to aperture width is greater than about 8:1.

18. (amended) A differential pressure measurement system coupleable to a process control loop and adapted to communicate a process variable output related to a differential pressure of a fluid flow within a fluid-carrying conduit, the system comprising:

a process pressure transmitter including:

a loop communicator coupleable to the process control loop and adapted for communication upon the process control loop;

at least one pressure sensor having first and second pressure inlets;

measurement circuitry coupled to the at least one pressure sensor and configured to provide a sensor output related to differential pressure between the first and second pressure inlets; [and]

a controller coupled to the measurement circuitry and the loop communicator, the controller adapted to provide a process variable output to the loop communicator, the process variable output related to the sensor output; and

a differential pressure measurement probe adapted for placement within the fluid-carrying conduit, the probe including:

a first plenum coupled to the first pressure inlet, the first plenum including a longitudinally extending impact surface with at least one impact aperture disposed to communicate pressure from the impact surface to the first pressure inlet;

a non-impact surface spaced from the impact surface, the non-impact surface having a non-impact aperture disposed to communicate pressure from the non-impact surface to the second pressure inlet.